A Study on Estimation Method of Interference State during Frequency Sharing in 5G Cellular Systems*

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***Abstract*—We have been studying a method to determine the interference tolerance capability of 5GNR based on the variation of communication quality due to co-channel interference (CCI) and to determine the frequency sharing decision, assuming co-channel sharing in 5GNR [1]. In this study, we used a local 5G radio, which is an actual 5GNR, and proceeded with quality evaluation when CCI was generated in a shielded environment within a radio blackout curtain. We also evaluated the performance of a method to identify the amount of CCI power from the quality evaluation results. Through experiments on actual equipment, we have achieved highly accurate identification of the amount of CCI power for both downlink (access from the base station to the terminal) and uplink (access from the terminal to the base station) during TCP/UDP communication. Here, we analyzed the feature importance, which indicates the importance as an identifier, and found that the RSRP (Reference Signal Received Power) was the most important among the various communication quality evaluation norms.**

***Index Terms*—Frequency Sharing, Co-Channel Interference, Machine Learning, Abnormal Detection**

I. INTRODUCTION

The explosive growth of radio frequency traffic for next-generation mobile communications has made it an important issue to cope with the tightness of frequency resources [6]. Frequency sharing, in which multiple systems share the same frequency resources to increase the efficiency of spatial and temporal utilization, is attracting attention as an effective solution to this problem [7]. In order to share frequencies among multiple systems, interference from one system to the other must be properly controlled so that both systems can establish communications with the required communication quality. There are two ways to control interference: one is to ensure spatial separation between the systems to sufficiently suppress interference [8], and the other is to control interference over time by using the frequency resources available when the other system is not in use [9]. In interference control that ensures spatial separation, the propagation distance of the interfering wave is estimated using a radio propagation model equation, and the radio transmission power and antenna directivity are controlled so that the interference from other systems is kept below a specified value. The usual radio propagation models are generalized and do not take into account the presence of shields that exist in the actual propagation environment, such as buildings that have a shielding effect on radio waves. As a result, there is a difference between the estimated interference and the actual interference. Such a difference in the given interference causes serious degradation of communication quality for other systems. To avoid this, the interference power is set higher than expected, and a margin is provided. As a result, even in the case of a difference between estimated and actual given interference, the generation of interference exceeding the assumption can be suppressed and degradation of communication quality can be avoided. The margin setting is decided upon consultation between systems sharing frequencies, but conservative sharing guidelines result in excessively large margins. As a result, the spatial separation distance required for sharing becomes large and the time available to use frequency resources is limited, and improvement of frequency utilization efficiency cannot be realized. Therefore, a possible way to avoid interference is to provide a mechanism that monitors the communication quality of the system sharing the frequency while it is actually communicating, and if the quality deteriorates beyond a certain level, it notifies the user that serious interference has occurred. Such a mechanism can reduce the margin required for interference protection and realize safe frequency sharing through interference protection by notification of the occurrence of interference. In addition, we surveyed recent research trends in next-generation communications [10] [11].

In this study, assuming frequency sharing between different systems in a 5G cellular system, we investigate a method to identify the occurrence of interference above a certain level by observing quality fluctuations due to mutual interference between systems. This method is assumed to work as an interference detection function in frequency sharing. In this study, a local 5G base station is assumed as a 5G cellular system. In local 5G, various quality evaluation values indicating communication quality were continuously observed using packet analysis software. RSRP, RSRQ (Reference Signal Received Quality), SINR (Signal to Interference plus Noise Ratio), MCS (Modulation and Coding Scheme), PDSCH Throughput were used. The variation of the quality evaluation values is then observed by firing signals from a signal generator that is a source of same-frequency interference. As a result, we clarify the relationship between the power of same-frequency interference and the quality evaluation value. Clarify the power of same-frequency interference that degrades local 5G communication quality, and establish a detection method to identify the occurrence of same-frequency interference by using the observation results of quality evaluation values under these conditions. Specifically, the relationship between quality evaluation values and same-frequency interference is determined by supervised learning, and the necessary criterion for identification is established. Then, we proceeded to evaluate the identification accuracy of undetermined same-frequency interference from actual quality evaluation values. From the machine learning-based identification method, we found that the quality evaluation values used in 5G systems can be used to identify same-frequency interference.

The paper is organized as follows: Section 2 presents the experimental environment model and the actual experimental scene; Section 3 introduces the basics of MCS as well as the dataset used in the experiment and experimental parameters; Section 4 shows the success rate of interference identification and feature importance for a total of four states of downlink and uplink in TCP/UDP; and Section 5 shows the feature importance for a total of four states in TCP/UDP. Section 5 summarizes the results of this study and discusses future prospects.

II. IDENTICAL INTERFERENCE DETECTION METHOD

A. *Quality Parameters Obtained from Packet Analysis*

The following information, which can be obtained from the header information specified in the 5G cellular system, was used as the quality evaluation value to observe the communication quality.

a) RSRP(Reference Signal Received Power): It is the received power of SSS (Secondary Synchronization Signal) per resource element; SSS is transmitted at a defined period and is not affected by the amount of traffic. The SS-RSRP is thus a basic parameter for evaluating the reception level of radio waves from a base station. It is a value that is determined mostly by the fixed installation conditions of the base station, such as its transmission power and antenna orientation and height, and by the measurement environment, such as distance from the base station and obstructions.

In RSRP, components other than the desired signal can be suppressed by detecting correlation with the synchronization signal, thus enabling highly accurate estimation of the received power of the desired signal. However, there is a possibility that interfering signal components may remain in the RSRP if the interfering signal has periodicity.

b) RSRQ(Reference Signal Received Quality): The RSRQ is an evaluation value that evaluates the reception quality. The RSRQ varies directly due to co-frequency interference; in the case of 5GNR, in the absence of interference, a theoretical Sub-Carrier Spacing (SCS) of -10.16 dB at 30 kHz and an SCS of -10.45 dB at 120 kHz are The maximum SCS is -10.16 dB at 30 kHz and -10.45 dB at 120 kHz.

An example of the RSRQ obtained in this study is shown in the figure1. The horizontal axis represents the measurement time and the vertical axis represents the RSRQ level. The legend shows the results without interference and with the signal generator power switched from -40 dBm to 15 dBm.

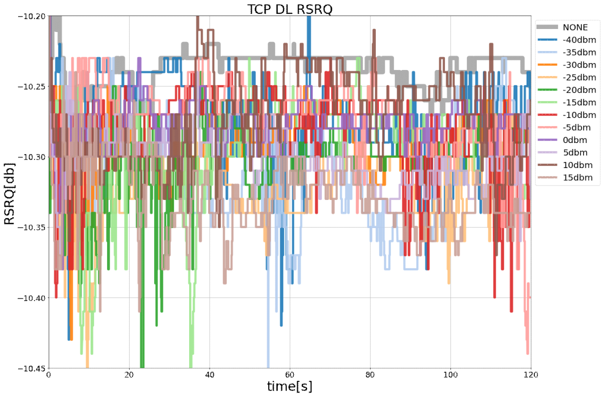


Fig. 1. RSRQ in TCP downlink

The figure1 shows that the generation of CCI tends to reduce the overall RSRQ value compared to the no-interference case. However, the decrease in RSRQ is not uniform for an increase in the same frequency interference power. Hence, the decreasing trend in RSRQ needs to be analyzed in order to use it for interference detection.

c) SINR(Signal to Interference plus Noise Ratio): SINR is not specified in the 5GNR standard, but may be detected by chip manufacturers as their own evaluation value. Therefore, although the exact calculation method has not yet been specified, a decrease in SINR is assumed to occur due to interference at the same frequency.

Since larger interference affects throughput, not only SS-RSRP but also SINR is considered to be a value that changes with interference. In SINR, the denominator is the interference power that exists in the same band as the SSS. Since it is difficult to measure the interference power directly, the dispersion of the ideal signal of the SSS is sometimes calculated to obtain the interference power. The interference power calculated in this way includes the noise component in addition to signals from neighboring cells in the same band.

In this study, the temporal variations were so large that no differences due to the occurrence of CCI could be seen in the raw data. Therefore, the feature creation described in Section 3 was performed to clarify the differences due to CCI as much as possible.

d) MCS(Modulation and Coding Scheme): As the throughput and modulation order decrease due to CCI occurrence, the MCS value tends to decrease as well. As an example, the figure2 shows the MCS variation in the UDP uplink. The horizontal axis shows the measurement time and the vertical axis shows the MCS value. The legend indicates no interference, -40 dBm output power from signal generation, -35 dBm output power from signal generation, ... 10 dBm output power from signal generation. From the figure2, it can be seen that the value of MCS decreases as the interference power increases.5GNR directly estimates and quantifies the quality state of the wireless transmission channel, such as

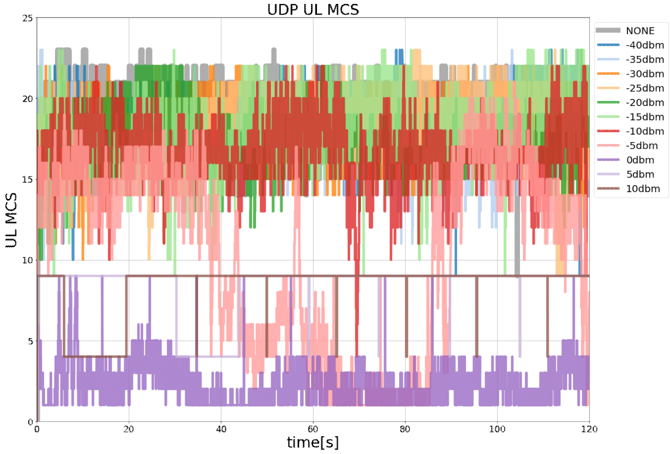


Fig. 2. MCS in UDP uplink

RSRP and RSRQ, and thus selects it while specifying the MCS for the evaluated value of quality.

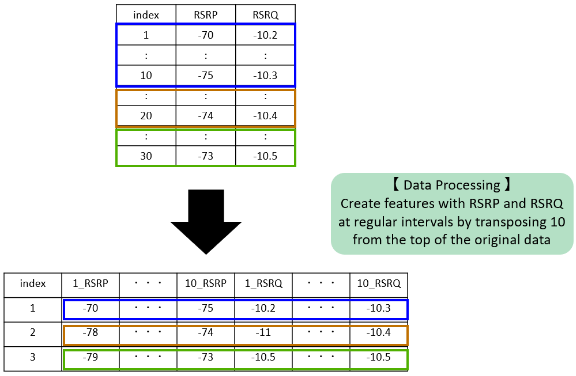
e) PDSCH(PhysicalDownlinkSharedChannel) /PUSCH(PhysicalUplinkSharedChannel)Throughput: It is a parameter in Layer 1 and is considered as a parameter for monitoring signal quality. In this study, throughput degradation due to CCI as well as MCS is observed from PDSCH and PUSCH.

B. Dataset used

The observed evaluation values are highly variable with respect to time. This is assumed to be due to instantaneous multipath fading. Even for the same frequency interference. The average interference power is assumed to be fixed, although it fluctuates due to multipath fading. In order to mitigate the fluctuations of multipath fading and to detect the fixed average interference power, the following process is performed when establishing the decision identifier.

a) Data Format for Identification of CCI: In this study, the data were thinned out according to the number of intervals to suppress the effects of fading and fluctuations in the values of the high-frequency components. By setting the number of intervals, it is possible to capture interference-induced fluctuations. If the number of intervals is input to the learning model without setting the number of intervals, overlearning can be prevented.

In this study, the number of intervals was set to 10 and the data was vectorized. Specifically, when the number of intervals is 10, the data is transposed every 10 data from the beginning. This processing method is performed for each parameter, and the processed data are merged in the column direction. In this way, the values of various parameters such as RSRP, RSRQ, and MCS are vectorized in one row of data. The figure3 below shows an image of feature creation.



index	RSRP	RSRQ
1	-70	-10.2
:	:	:
10	-75	-10.3
:	:	:
20	-74	-10.4
:	:	:
30	-73	-10.5

【 Data Processing 】
Create features with RSRP and RSRQ
at regular intervals by transposing 10
from the top of the original data

index	1_RSRP	· · ·	10_RSRP	1_RSRQ	· · ·	10_RSRQ
1	-70	· · ·	-75	-10.2	· · ·	-10.3
2	-78	· · ·	-74	-11	· · ·	-10.4
3	-79	· · ·	-73	-10.5	· · ·	-10.5

Fig. 3. Imaged figure of feature creation

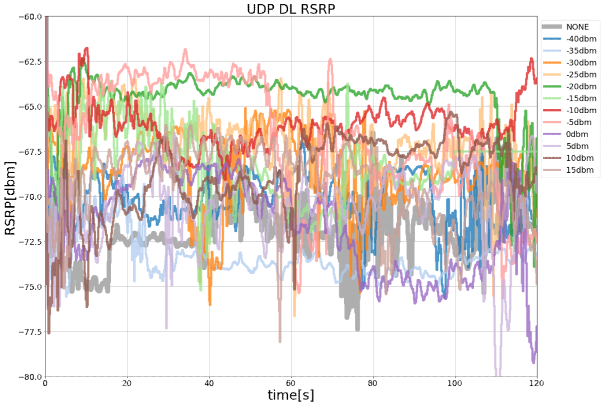


Fig. 4. RSRP data before processing

Using such interval-based features, it is possible to capture the movement of data with respect to time variations. As an example, the figure4 and the figure5 show the data fluctuation before and after the creation of features for the number of intervals in the UDP downlink. The figure4 shows that the raw data before feature generation has a large time variation, and it is difficult to see the difference due to the interference power. On the other hand, the figure5 shows the graph of RSRP at each given interference power when the feature creation was performed by setting the number of intervals. Comparing the figures4 and the figures5, it can be seen that the difference in interference power is clear. The reason for this can be attributed to the fact that by capturing the feature values over a long interval, fluctuations in the values are also added to the feature values. As a result, although it is difficult to discriminate before creating the features, taking the number of intervals reduces the identification error. This is used as the input data for interference identification.

In this study, the feature creation using the number of intervals leads to improved identification accuracy by clarifying the difference in interference power.

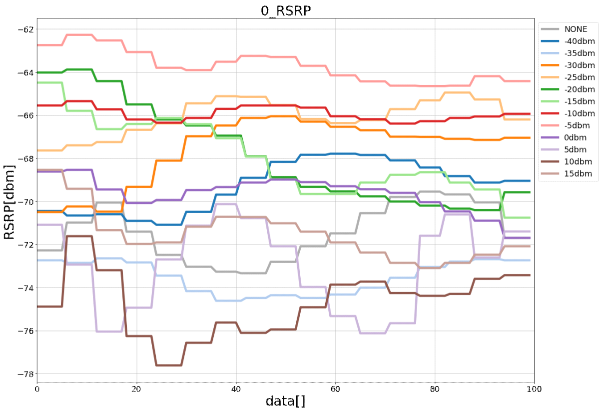


Fig. 5. RSRP data after processing

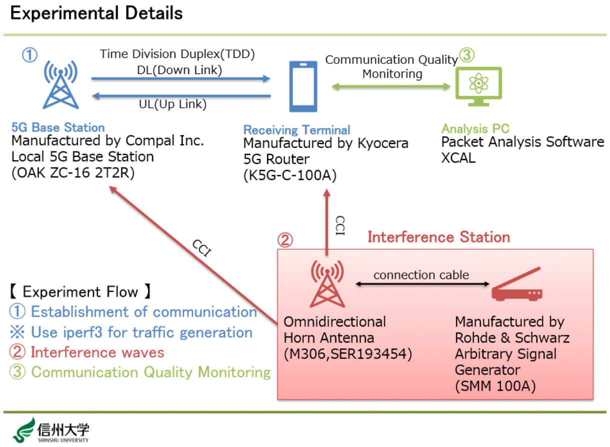


Fig. 6. Experimental Environment Model

b) Data Sets and Evaluation Methods: In this study, two types of access methods were considered: downlink, which is access from the base station to the terminal, and uplink, which is access from the terminal to the base station. In addition, two types of transport layer protocols, TCP and UDP, were assumed. Hence, the following four streams were assumed:1,UDP downlink2,UDP uplink3,TCP downlink4,TCP uplink. In each stream, packet analysis included ”1” for data with no interference and ”2” for data with an output interference power of -40[dBm] from the signal generator.…. Supervised learning was used, labeling data with an output interference power of 15[dBm] from the signal generator as ”13”. Machine learning random forests, which have been shown to be significant in previous studies [5], were used for identification. The labels corresponding to the output interference power were identified with the parameters obtainable by packet analysis as explanatory variables and the labels from 1 to 13 as objective variables.

The data obtained were RSRP, RSRQ, SINR, MCS, and PDSCH (PUSCH) Throughput. To determine which identifier was most important, the identification success rate was calculated when four of the five were used as identifiers. In addition, the feature importance, which indicates the contribution to the identification, is also shown at the same time, so that we can know which identifiers are effective as identifiers.

III. EXPERIMENTAL DETAILS

The experimental environment model for this experiment is shown in the figure6. The locations indicated in blue in the figure, the local 5G base station (OAK ZC-16 2T2R) manufactured by Compal and the 5G router (K5G-C-100A) manufactured by Kyocera, are assumed to be the primary system that can preferentially use frequency resources under the assumption of frequency sharing. In local 5G, the downlink and uplink are switched in time (TDD). iperf3 was used for packet traffic generation. The communication method is TCP/UDP, and the amount of data transmission in iperf3 is set to a sufficiently large value in order to assume a full buffer state where packets are always generated. Next, after communication is established, CCI is generated from the interfering station, which is indicated in red in the figure. The interfering station used an omni-directional whip antenna (M306, SER193454) as a radiating antenna and a Rohde & Schwarz arbitrary signal generator (SMM 100A) as a CCI generator. Packet analysis software (XCAL) was used on the Kyocera 5G router to analyze packets at all times. As a result, the transmission speed and data arrival interval are analyzed using the packet header information, and the communication quality of the primary system is constantly monitored.

The following figure7 shows the actual experiment. In this experiment, the equipment was placed inside a tent formed by a radio shield, and the experiment was conducted in an environment where the leakage of radio waves to the outside was kept below a very low level. An attenuator of about 23 dBm was inserted between the signal generator and the whip antenna to prevent reflections when interference was applied. When the session of the assumed primary system was lost due to interference, the local 5G base station or the Kyocera 5G router was restarted to restore communication.

A. Test Specification

The tableI below shows the experimental parameters. The communication was conducted without moving the terminal and keeping the distance from the base station constant. In this experiment, the output power from the signal generator was used as the interference power, and interference was applied with a resolution of 5 dbm intervals.

The transmitting power of the base station is higher than that of the terminal. Therefore, the uplink, where the terminal is the transmitter, has a lower quality than the downlink because the ratio of interference power to transmit power is smaller. On the downlink, the desired power is higher, resulting in higher communication quality and, consequently, a more stable quality rating. On the other hand, the quality of the uplink is low, and attempts to stabilize it through quality control such as

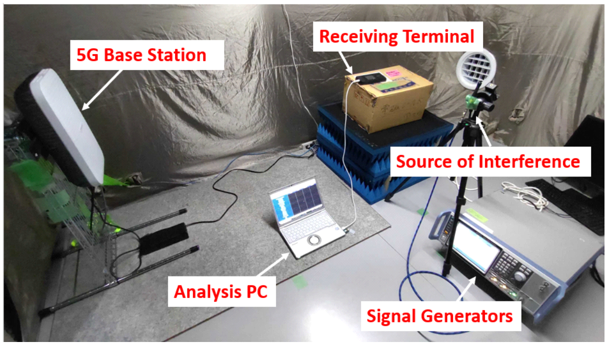


Fig. 7. Experimental Scene

TABLE I
TEST SPECIFICATION

Data Item	Special Characteristic	Unit
Measuring Channels		
Bandwidth(measured Value)	16.5	MHz
Central frequency	4804.31	MHz
SCS(SubCarrierSpacing)	30	kHz
Iperf3		
Bandwidth	600	MHz
Transmission time	120	s
Communication method	TCP/UDP	
Buffer length	1400	Byte
Distance between base station and terminal	160	cm
Output Interference Power from Interference Stations	-40,-35,-30,-25,-20,-15, -10,-5,0,5,10,15	dBm

MCS switching tend to result in large fluctuations in achieved throughput.

IV. RESULTS OF EXPERIMENTS

The experimental results for the identification success rate and feature importance in each state are shown below. The numbers in the leftmost column correspond to ”1” for data with no interference, ”2” for data with an output interference power of -40[dBm] from the signal generator . . . . 13” corresponds to data with an output interference power of 15[dBm] from the signal generator, respectively; for the TCP/UDP uplink, when the output power from the signal generator is 15dbm, the communication in the primary system is broken because The data up to ”12” with an output power of 10 dbm from the signal generator was evaluated.

From the tableII and the tableIII, it can be seen that a high identification success rate was achieved for each interference condition. It can also be seen that RSRP is superior in terms of feature importance. The RSRP is essentially a pilot signal, which is suppressed by averaging when the interfering signal is irregular in calculating the desired power. However, the given interference signal generated from the signal generator transmits a constant modulation signal periodically. As a result of this periodic nature of the given interference, the suppression of the given interference component by correlation detection of the RSRP is limited, and the residual component of the given interference is detected as a variation of the RSRP.

TABLE II
UDP DOWNLINK IDENTIFICATION SUCCESS RATE

	PDSCH Throughput without	MCS without	SINR without	RSRQ without	RSRP without
1	73	75	93	48	28
2	100	100	100	100	100
3	98	100	100	100	98
4	100	100	100	100	100
5	100	100	100	100	100
6	100	100	100	100	100
7	100	100	100	100	100
8	100	100	100	100	100
9	100	100	100	100	100
10	100	100	100	100	100
11	100	100	100	96	100
12	97	97	100	100	97
13	98	100	100	100	100

TABLE III
UDP DOWNLINK FEATURE IMPORTANCE

	PDSCH Throughput without	MCS without	SINR without	RSRQ without	RSRP without
RSRP	51	41	50	51	0
RSRQ	24	22	22	0	25
SINR	25	19	0	24	37
MCS	0	0	0	0	0
PDSCH Throughput	0	18	28	25	38

From the tableIV and the tableV, it can be seen that the feature importance of RSRP is the same as in the downlink, but the feature importance of MCS is increased by several percent. This can be attributed to the fact that the Kyocera 5G router (K5G-C-100A) has a small transmission power and the MCS for quality control compensates for quality fluctuations caused by the given interference. Similar results were also obtained in the case of TCP uplink communication.

The results for the TCP downlink in terms of identification success rate and feature importance are shown in the tableVI and in the tableVII.Compared to the UDP downlink, the RSRQ is the identifier with the largest contribution as a feature importance. This may be due to the fact that the value difference due to interference power was clearer for RSRQ. However, it can also be seen that the feature importance of RSRP is also the next largest.

From the TableII, TableIV, and TableVI, it can be seen that the same interference detection method in this study achieved more than 95% identification accuracy in the presence of interfering waves with labels 2 to 13, and in most cases, 100% identification accuracy was achieved. On the other hand, the identification accuracy in the interference-free condition is at least 28%, and there is room for improvement.

TABLE IV
UDP UPLINK IDENTIFICATION SUCCESS RATE

	PUSCH Throughput without	MCS without	SINR without	RSRQ without	RSRP without
1	85	90	93	83	50
2	100	100	100	100	97
3	100	100	100	100	98
4	100	100	100	100	95
5	100	100	100	100	98
6	100	100	100	100	100
7	100	100	100	100	100
8	100	100	100	100	100
9	100	100	100	100	100
10	100	100	100	100	100
11	100	100	100	100	100
12	100	100	100	100	100

TABLE V
UDP UPLINK FEATURE IMPORTANCE

	PUSCH Throughput without	MCS without	SINR without	RSRQ without	RSRP without
RSRP	78	73	76	74	0
RSRQ	9	7	6	0	24
SINR	8	6	0	6	26
MCS	5	0	4	5	13
PDSCH Throughput	0	14	14	15	37

TABLE VI
TCP DOWNLINK IDENTIFICATION SUCCESS RATE

	PDSCH Throughput without	MCS without	SINR without	RSRQ without	RSRP without
1	95	95	95	73	83
2	100	100	100	100	100
3	100	100	100	100	100
4	100	100	100	95	100
5	100	100	100	100	100
6	100	100	100	100	100
7	100	100	100	100	100
8	100	100	100	100	100
9	100	100	100	100	100
10	100	100	100	100	100
11	100	100	100	100	100
12	100	100	100	100	95
13	100	100	100	100	100

TABLE VII
TCP DOWNLINK FEATURE IMPORTANCE

	PDSCH Throughput without	MCS without	SINR without	RSRQ without	RSRP without
RSRP	25	24	24	62	0
RSRQ	73	73	73	0	78
SINR	2	1	0	16	11
MCS	0	0	0	1	0
PDSCH Throughput	0	2	3	21	11

V. CONCLUSION AND FUTURE PROSPECTS

The purpose of this study was to identify the amount of interference power by monitoring the receiving terminal during communication using the actual local 5G radio equipment of 5GNR to proceed the quality evaluation when CCI is generated in a shielded environment in a radio dark screen. As a result, highly accurate identification results were achieved using machine-learning random forest with five identifiers (RSRP, RSRQ, SINR, MCS, and PDSCH Throughput). It was also shown that RSRP is effective as an identifier with high feature importance when the interfering wave is a continuously modulated signal.

Future prospects are to monitor communication quality by upper layers such as throughput and MCS, and to predict future values by using less prior data.

ACKNOWLEDGMENT

These research results were obtained from the commissioned research (No.02601) by National Institute of Information and Communications Technology(NICT), Japan

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